SENIOR THESIS PROPOSAL

S.T.E.P.S. Building

Lehigh University

Bethlehem, PA

Joseph S. Murray, Structural Option

Faculty Advisor: Linda Hanagan

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Executive Summary

The S.T.E.P.S. Building in Bethlehem, PA sits on Lehigh University's campus. It is a mixed use facility consisting of laboratories, lecture halls, and faculty offices. The building is divided into two main wings which are bridged by a central atrium.

The structural system of the building consists of semi-rigid moment frames and full moment frames. It uses a composite floor as a rigid diaphragm to transfer lateral loads imposed on the façade to the beams and girders. The beams and girders then transfer these loads through their moment connections to a network of mainly W14 columns. The columns finally transfer the load into the soil through a combination of spread footings and mat foundations.

The proposed structural breadth consists of three major tasks. First, the semi-rigid wind clips will be replaced with braced framed and full moment connections. Second, the floor system will be checked against vibration control tolerances and redesigned as necessary. Third, any suspicious locations which may produce conflicts in steel erection will be examined and redesigned.

The two proposed breadths are related to architectural and construction management considerations. As a consequence of adding braced frames at certain location, an architectural study of the braces will be undertaken. Any potential conflicts should be resolved with respect to head room and pedestrian pathways through the building. The construction management breadth consists of a detailed construction sequence with crane positioning. An examination of the possibility of prefabricating and shop welding as much as possible will also be undertaken to see potential cost savings from the reduction in field welds and erection time.

A proposed schedule is provided which has four milestone dates. These milestones are:

1. 1/28/13 Redesign lateral system and floor system
2. 2/11/13 Finalize computer model
3. 3/1/13 Analyze foundation and connections
4. 3/25/13 Complete research and analysis of breadth topics

Building Introduction

Lehigh University envisioned the Science, Technology, Environment, Policy, and Society (S.T.E.P.S.) Building as a way to attract new students and retain existing students in the science and engineering fields. A picture of the building is in Figure 1. The university lacked a modern laboratory building with all the amenities that have come with increases in technology over the years. In an interesting and experimental fashion, the departments have been intermixed by Health, Education & Research Association, Inc. They believe it will lead to increased communication and collaboration among faculty and researchers of various disciplines.

Figure 1: South Façade

Image Courtesy of Lehigh University

The building is oriented on the corner of East Packer Ave. and Vine St. as shown in Figure 2. The streets do not intersect at a 90 degree angle. The architects decided to use site lines to orient the building, which led to the nonlinear shape of the façade along Vine St.

Figure 2: Site Plan

Image Courtesy of BCJ Architects

Lehigh University slowly purchased the properties which were on the building site as they planned for a building to be put there. The location was ideal for expanding campus activities close to the campus core. This is shown in Lehigh's Campus Master Plan of 2000 in Figure 2.

Figure 2: Campus Master Plan

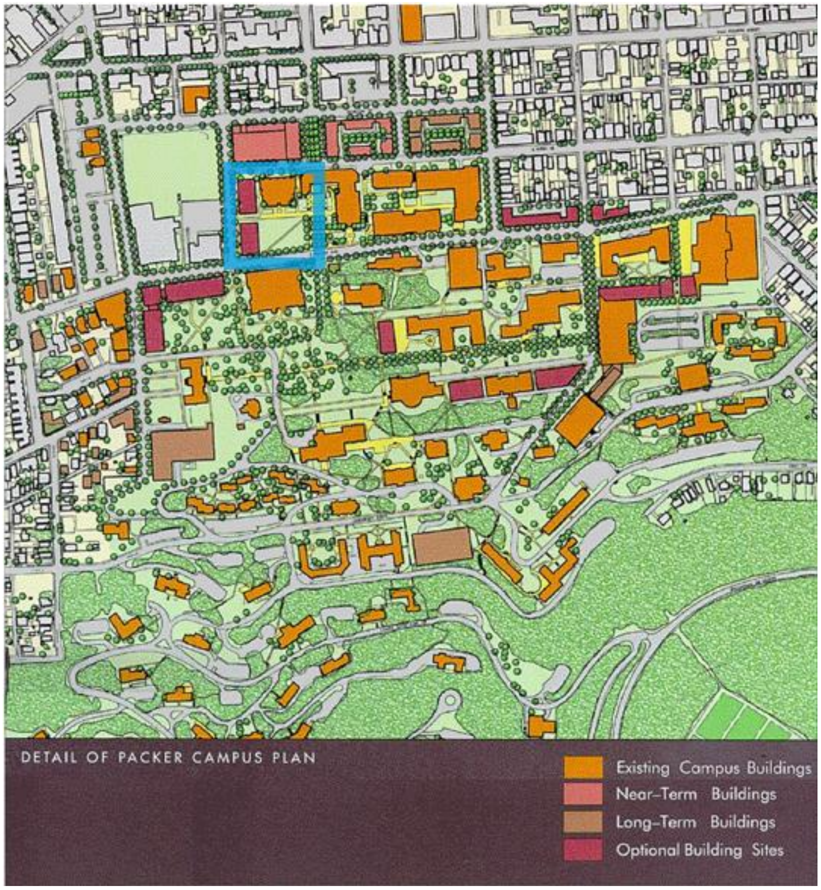


Image Courtesy of Lehigh University

The building is also connected to an existing structure through the use of a raised pathway that is enclosed. This further encourages interconnectivity between faculty, researchers, and students, because the adjoining building contains part of the College of Social Sciences. Between this adjacent building and S.T.E.P.S., there is a large open lawn. The university made a significant effort to maintain this lawn for extracurricular activities such as frisbee, croquet, and football. The S.T.E.P.S. Building is divided into three wings for the purpose of this analysis. These wings are diagramed in Figure 3.

Figure 3: Wings A, B, and C of S.T.E.P.S. Building

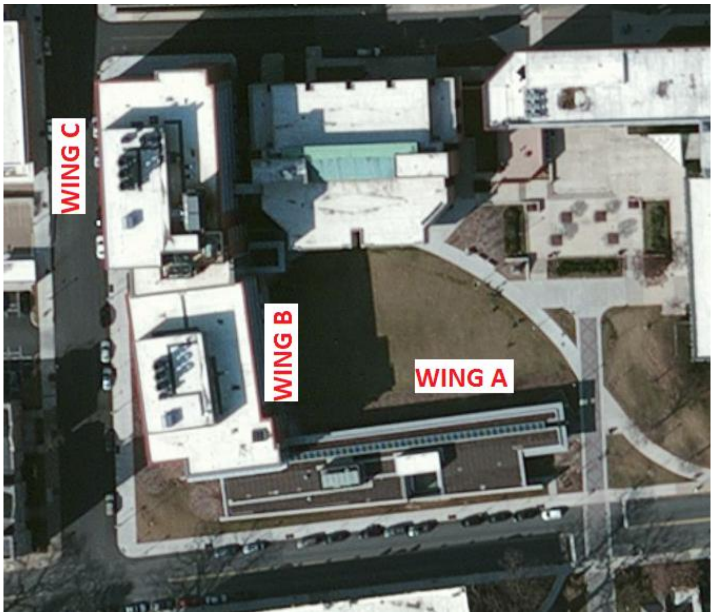


Image courtesy of Bing.com

Wing A is a one story structure with a lounge and entryway. It has raised clearstories to allow for natural daylight to illuminate the space. It also has a 12" deep green roof supported by structural wood which helped in earning LEED Certification. The building is LEED Gold certified by the United States Green Building Council (USGBC). Because of its limited building height, Wing A will not be analyzed in this report.

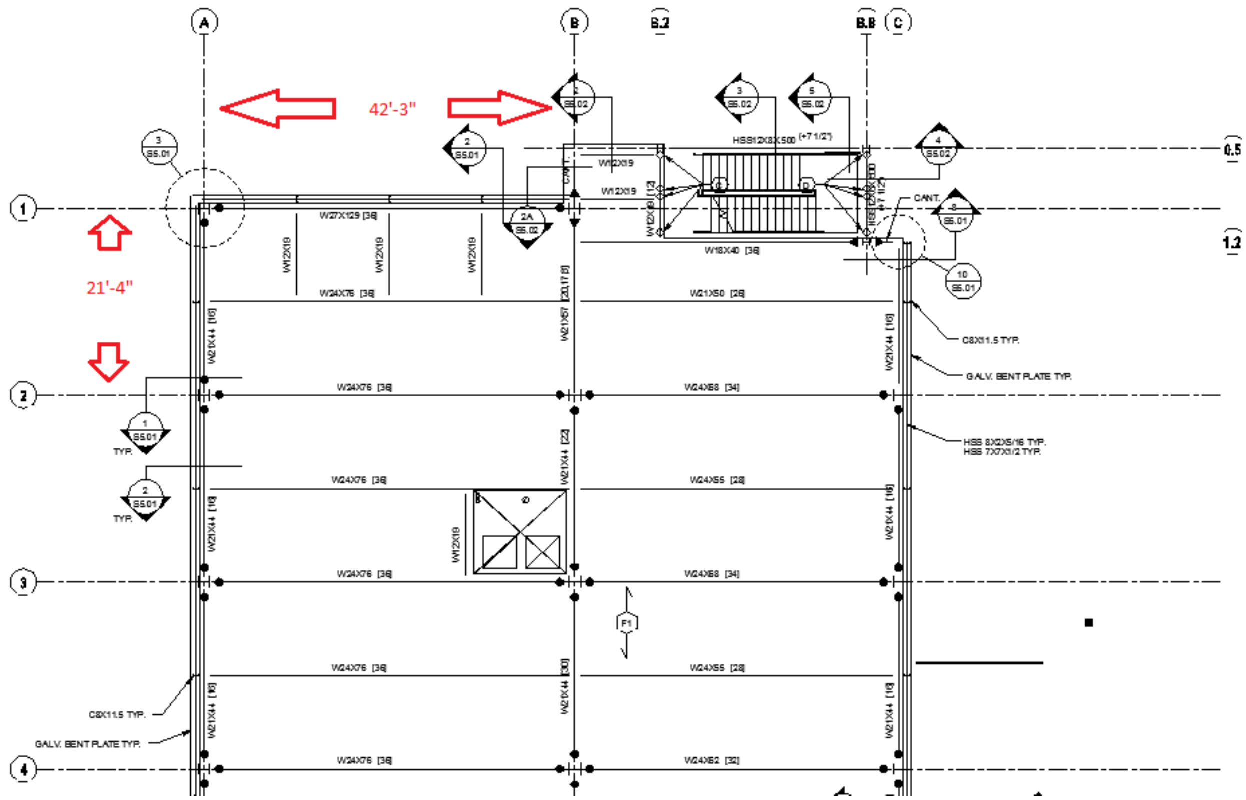
Wing B is a four story steel framed structure oriented along Packer Ave. There is a large atrium with lounge areas connecting Wing B to Wing C on each floor. Wing C is also steel framed and is 5 stories.

The gravity and lateral load resisting elements continue uninterrupted through the atrium. As a result, Wing B and Wing C will be treated as one building. The building's lateral system consists of moment connections between columns and beams throughout the building.

Sustainable features of the building include the green roof, high-efficiency glazing, sun shading, and custom mechanical systems.

Structural System

Figure 4: Typical Building Floor Plan



For a full floor plan, see Appendix A-1.

Floor System

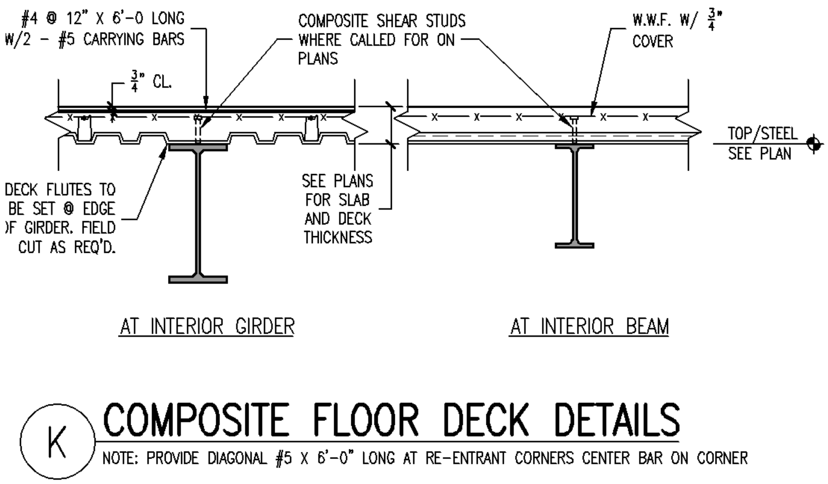
There is a composite steel deck floor system in place for all floors in Wings B & C above grade. Basement floors are slab on grade.

Along Vine St., which will be considered the longitudinal direction of the building, typical girders have a center to center span of 21'-4" with one intersecting beam at their midpoint. The transverse beams which run parallel to Packer Ave. have a span anywhere from 36'-11" to 42'8".

The decking is a 3" deep 18 gauge steel deck with 4-1/2" normal weight concrete topping and welded wire fabric. The bulk of the decking is run longitudinally throughout Wings B & C and has a span of 10'8" between beam centerlines. The exceptions to this are two bays to the very south of Wing B along Packer Ave. These bays are oriented transversely. The total thickness ends up being 7-1/2" with a 6x6" W2.9 x

W2.9 welded wire fabric embedded ¾" from the top of the slab. Figure 5 shows a typical detail of the composite floor decking.

Figure 5: Composite Floor Deck Detail



The floor system is supported by wide flange beams designed as simply supported. A combination of full moment connections, semi-rigid moment connections, and shear connections are used. Typical sizes for transverse beams are W24x55 and W24x76. The girders are W21x44. Most beams have between 28 and 36 studs to transfer shear. Figure 5 shows a typical Full Moment Connection with field welds noted. Figure 6 shows the entirety of the first floor system for Wing B. Figure 8 shows the entirety of the first floor system for Wing C.

Vertical Members

Wide flange columns are used throughout the building for gravity loads. They are arranged for strong axis bending in the transverse direction. Most spans have a column at either end with another at the midpoint.

W14 is the most common section size with weights varying from W14x90 all the way up to W14x192 on the lower floors.

Foundation

Schnabel Engineering performed a geotechnical analysis of the site in 2007. This concluded that the soil had sufficient bearing capacity to support the loads from the building.

Interior columns are supported by a mat foundation 18' wide and 3'-6" deep shown in Figure 6 and Figure 7. Exterior columns bear on square footings ranging from 11'x11' to 16'x16' with depths from 1'6" to 2'. These are tied into the foundation by base plates with concrete piers.

Figure 6: Mat Foundation Plan View

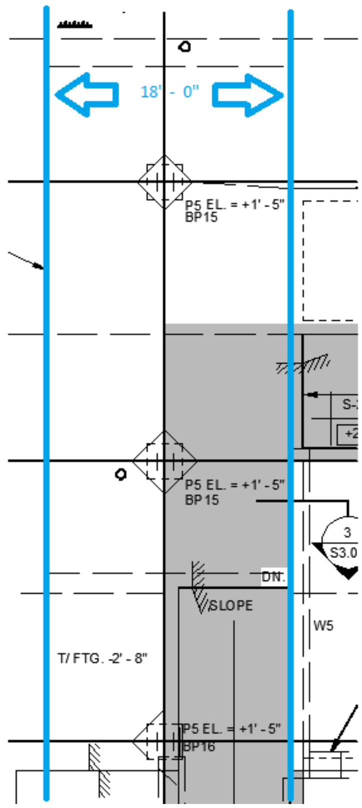


Figure 7: Mat Footing Schedule

MF1	* X 18'-0" X 3'-6"	#9 @ 12" O.C. E.W. BTM #9 @ 12" O.C. LONG, TOP #7 @ 12" O.C. TRANS, TOP	SEE PLAN FOR LENGTH

The reinforced foundation walls have strip footings ranging from 2' to 6' wide with depths between 1' and 2'. These are monolithically cast with the piers for the exterior columns.

Roof System

The roof decking consists of a 3" 16 gauge steel roof deck with a sloped roof for drainage. Topping ranges from ¼" to 4-1/2" to achieve a ¼":1' slope. Therefore, total thickness ranges from 3-1/4" to 7-1/2". Framing is similar to floor framing with wide flanges ranging from W24x55 to W24x68.

The floor system has increased loads where the mechanical penthouses are situated. The penthouse itself is framed with square HSS tubing. Heavier W27x84 wide flange beams support this area.

<u>Lateral System</u>

The building resists lateral loads by moment connections at the beam to column locations. They are continuous throughout the building and beams are designed as simply supported for gravity loads. The moment connections are designed only to take lateral loads. A typical semi-rigid moment connection is shown in Figure 8. Many of these moment connections are semi-rigid connections to give the system more flexibility. An example of layout of the two types of moment connections in the floor plan is shown below in Figure 9. The triangles are full moment connections and the dots are semi-rigid.

<u>Figure 8: Typical Semi-Rigid Moment Connection</u>

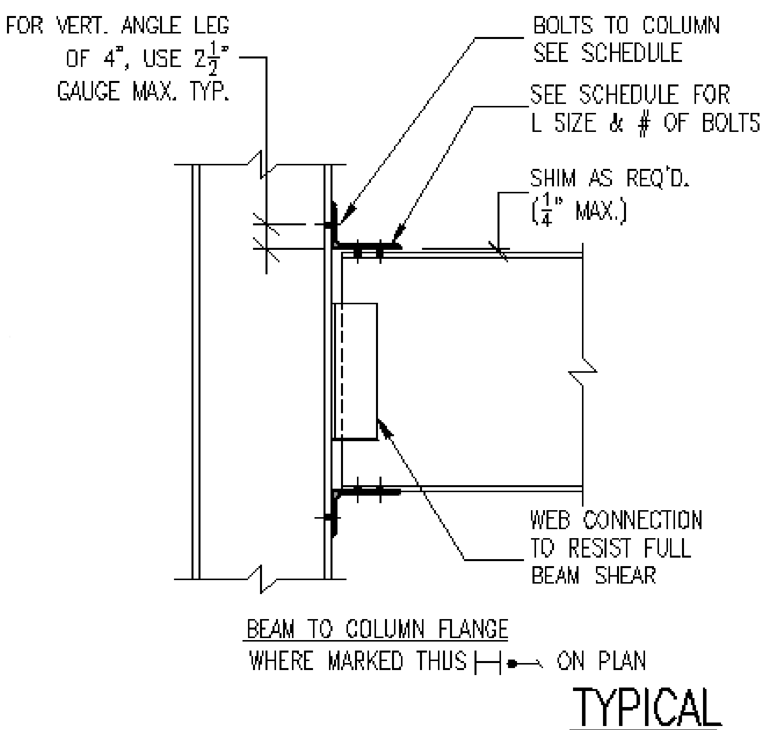
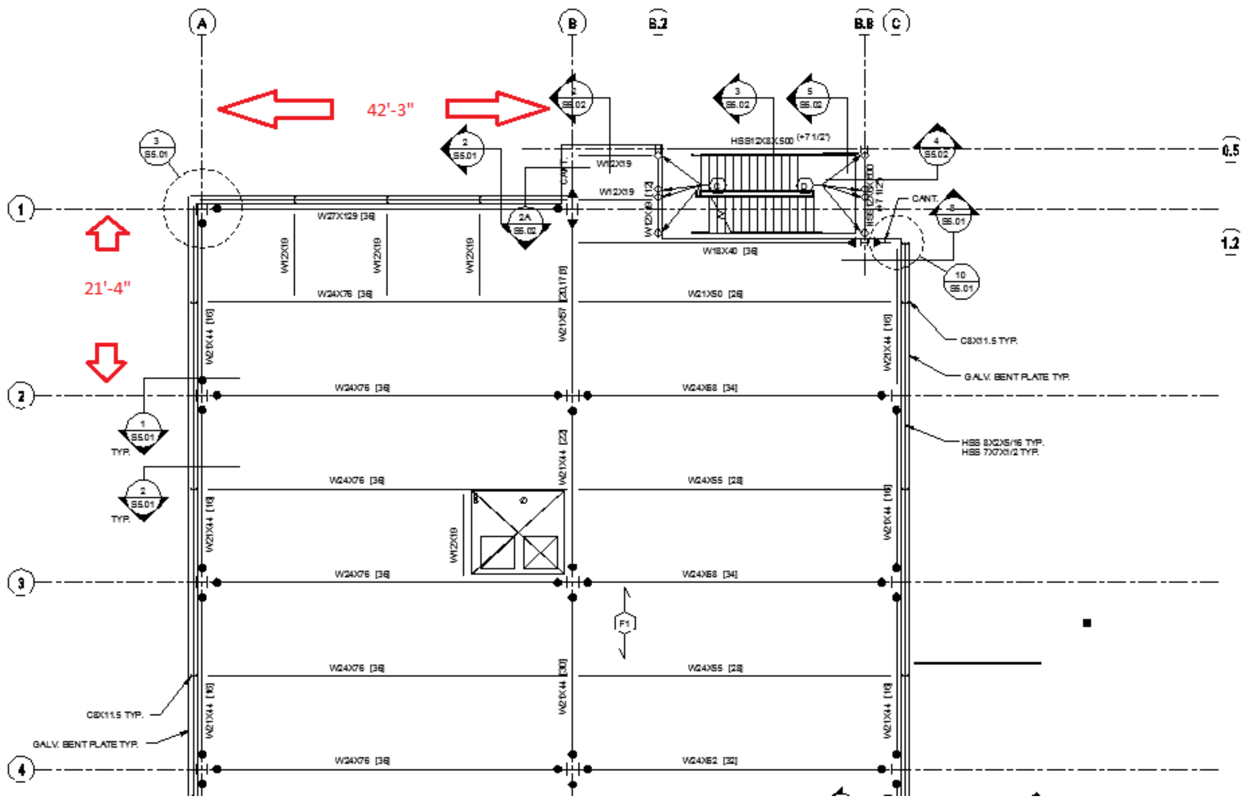


Figure 9: Typical floor plan with bay sizes



The lateral loads seen in the Penthouse are going to be the greatest based on height. At the highest Penthouse roof level, there are moment connections in the transverse direction and single angle braced frames in the longitudinal direction. The connections to the roof of the building are rigidly connected to the roof framing members. These members then transfer the load to flexible moment connections in the columns supporting the roof. These roof members are a larger W27x102 compared to adjacent members such as W24x68 or W27x84.

Design Codes

The primary design code used to construct the S.T.E.P.S. Building was the Pennsylvania Uniform Construction Code (PUCC). The PUCC is the primary code adopted by the city of Bethlehem, Pennsylvania. The PUCC is based on the International Code Council (ICC). When design was completed in 2008, the 2006 PUCC referenced the following codes:

2006 International Building Code

2006 International Electrical Code

2006 International Fire Code

2006 International Fuel Gas Code

2006 International Mechanical Code

ASCE 7-05, Minimum Design Loads for Buildings and Other Structures

AISC Steel Construction Manual, 13th Edition

ACI 318-05, Building Code Requirements for Structural Concrete

ACI 530-05, Building Code Requirements for Masonry Structures

The primary codes employed in analysis were the AISC Manual and ASCE 7-05

Design Loads

Live Loads

Table 1: Live Load Values

Occupancy	Design Load on Drawings	ASCE 7-05 Load (Tables 4-1, C4-1)
Office	50 PSF	50 PSF + 20 PSF (Partitions)
Classroom	40 PSF	40 PSF
Laboratory	100 PSF	100 PSF
Storage	125 PSF	125 PSF
Corridors/Lobbies @ Ground Level	100 PSF	100 PSF
Corridors Above Ground Level	80 PSF	80 PSF

Dead Loads

Table 2: Calculated Dead Load

	Dimension	Unit Weight	Load (PSF)
3” 18 Ga. Composite Deck			2.84
4-1/2” Topping			75
Self-Weight			5
MEP Allowance			10
Ceiling Allowance			5
TOTAL			**97.84 PSF**

Roof Live Load

Table 3: Roof Live Load

Occupancy	Design Load on Drawings	ASCE 7-05 Load (Tables 4-1, C4-1)	Design Load
Roof	N/A	20 PSF	**20 SF**

Roof Dead Load

Table 4: Roof Dead Load

	Dimension	Unit Weight	Load (PSF)
3" 16 Ga. NS Roof Deck			2.46
3" Concrete Topping (Avg.)	0.290 CF/SF	150	43.5
Self-Weight			5
Roofing Allowance			10
TOTAL			**60.96 SF**

Roof Snow Load

Uniform Roof Snow Load

Table 5: Uniform Roof Snow Load

Design Factor	ASCE 7-05	Design Value
Snow Load (Pq)	Figure 7-1	30 PSF
Roof Exposure	Table 7-2	Fully Exposed
Exposure Type	Section 6.5.6.2	B
Exposure Factor (Ce)	Table 7-2	.9
Thermal Factor (Ct)	Table 7-3	1.0
Building Type	Table 1-1	III
Importance Factor (I)	Table 7-4	1.1
Flat Roof Snow Load (Pf)	Equation 7-1	20.8 PSF
Minimum Snow Load (Pf,min)	Section 7.2	22 PSF
Design Snow Load	Section 7.2	**22 PSF**

Pf = 0.7(Ce)(Ct)(I)(Pq)

Pf = 0.7(.9)(1.0)(1.1)(30) = 20.8 PSF

20.8 < Pf,min = 22 → Use 22 PSF as the Design Snow Load

5.5.2 Drift Snow Load

NOTE: For simplification of this analysis, snow drift was not considered.

Penthouse Live Load

Table 6: Penthouse Live Load

Occupancy	Design Load on Drawings	ASCE 7-05 Load (Tables 4-1, C4-1)	Design Load
Mechanical Room	N/A	200 PSF	**200 PSF**

Penthouse Dead Load

Table 7: Penthouse Dead Load

	Dimension	Unit Weight	Design Load (PSF)
3” 18 Ga. Composite Deck			2.84
4-1/2” Concrete Topping			75
Self-weight			5
MEP Allowance			10
Ceiling Allowance			5
TOTAL			**97.84 PSF**

Brick Façade Load

Table 8: Brick Façade Load (Per Level)

	Height	Unit Weight (PSF)	Design Load (PLF)
Brick Veneer	10'-3"	40	410
2" Rigid Insulation	10'-3"	1.5	15.375
Cold Formed Steel Framing	10'-3"	1	10.25
Gypsum Wall Board (5/8")	10'-3"	2.5	25.625
Window (Glass, Frame, Sash) (ASCE 7-05 Table C3-1)	5'-1"	8	40.8
TOTAL			**502.1 PLF**

Glass Curtain Wall Load

Table 9: Glass Curtain Wall Load (Per Level)

	Dimension	Unit Weight (PSF)	Design Load (PLF)
Window (Glass, Frame, Sash) (ASCE 7-05 Table C3-1)	15'-4"	8	**122.4 PLF**

Penthouse Wall Load

Table 10: Penthouse Wall Load

	Dimension	Unit Weight (PSF)	Load (PLF)
Metal Wall Panel	16'-4"	5	81.7
Steel Framing	16'-4"	2	32.7
Bracing Allowance	16'-4"	3	49
TOTAL			**163.4 PLF**

Problem Statement

The structural system of the S.T.E.P.S. building has been proven to be adequate for strength and serviceability requirements in Technical Reports 1, 2, and 3. The lateral force resisting system is almost entirely composed of semi-rigid wind clips throughout the building which are not designed for full moment capacity. Although earthquake forces do not control design for S.T.E.P.S., these wind clip connections have questionable reliability in the event of a seismic event. The floor system was designed for floor vibrations typical of a laboratory, although this has not been confirmed through analysis. The floor typically consists of W21 girders with a 7" deep concrete composite decking. W24's typically frame into the girders, which could result in some construction issues during erection with respect to connections.

Problem Solution

In order to design a more effective and trustworthy lateral system, the wind clips will be replaced with braced frames in the transverse direction of the building and full moment frames in the longitudinal direction. These types of lateral systems when designed correctly perform much better than the wind clips, especially in the case of a seismic event. Figure 9 has the floor plan revisions for Wing B, and Figure 10 has the floor plan revisions for Wing C. The braced frames are shown as red lines, and the moment frames are shown as blue triangles. All semi-rigid connections, currently marked as black dots, will be changed to shear or full moment connections as appropriate.

Vibration control tolerances will be researched, and the existing floor system will be analyzed for its performance in eliminating unnecessary floor vibrations. Alternative floor systems will be investigated and analyzed as appropriate according to the acceptable vibrations allowed in a laboratory setting. If any of these alternate floor systems have distinct advantages over the existing floor, the floor system will be redesigned.

The braced frames which will be replacing the lateral system will be designed in complete detail including gusset plate connections to the beams and columns. The new typical full moment connections will also be looked at in detail. Spot checks will be made of any suspicious locations where two joining elements may produce an issue in erection. These connections will be redesigned as necessary, and a comparison between the existing system and proposed system will be made.

Figure 9: Revised Structural Floor Plan for Wing B

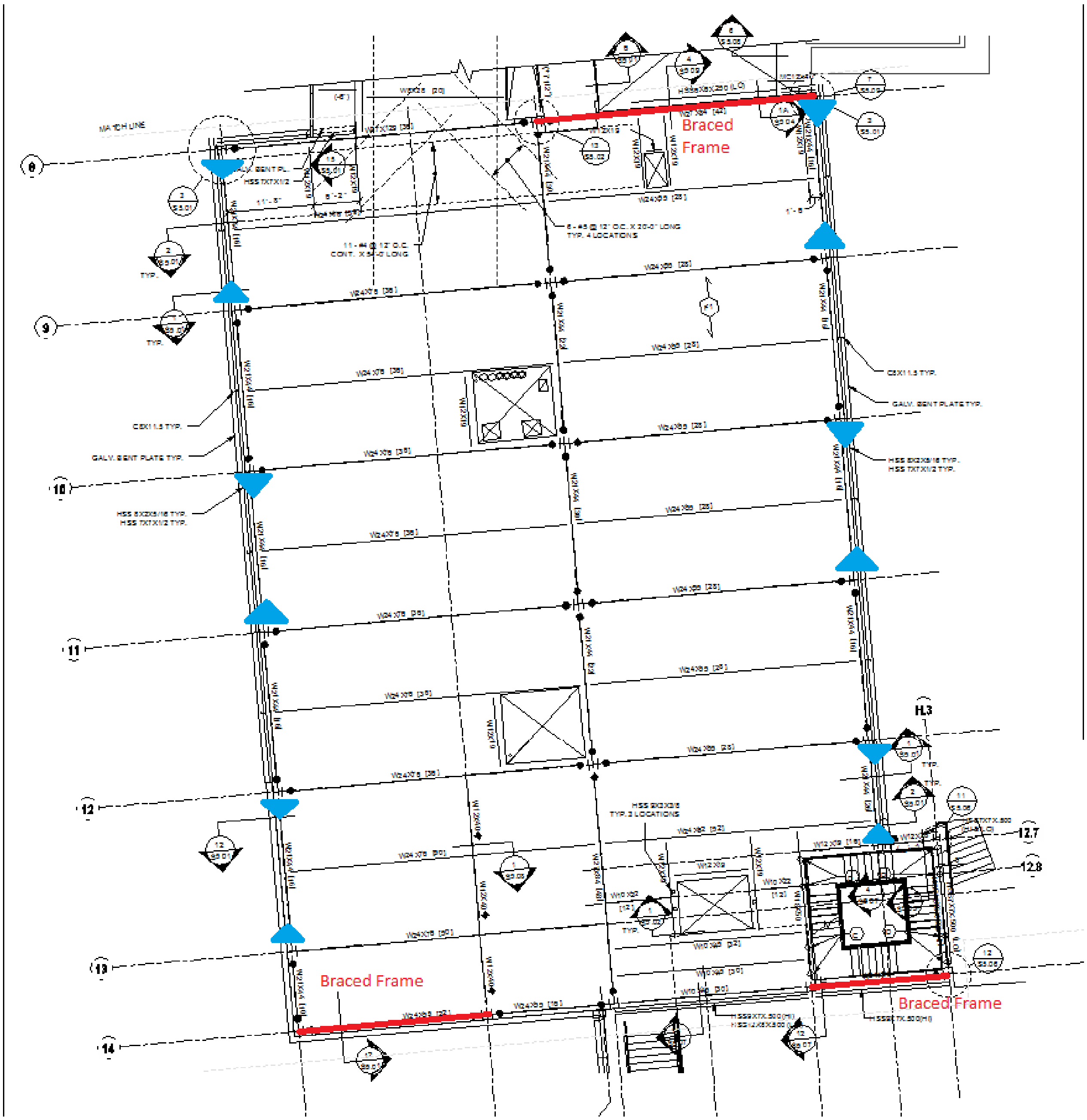
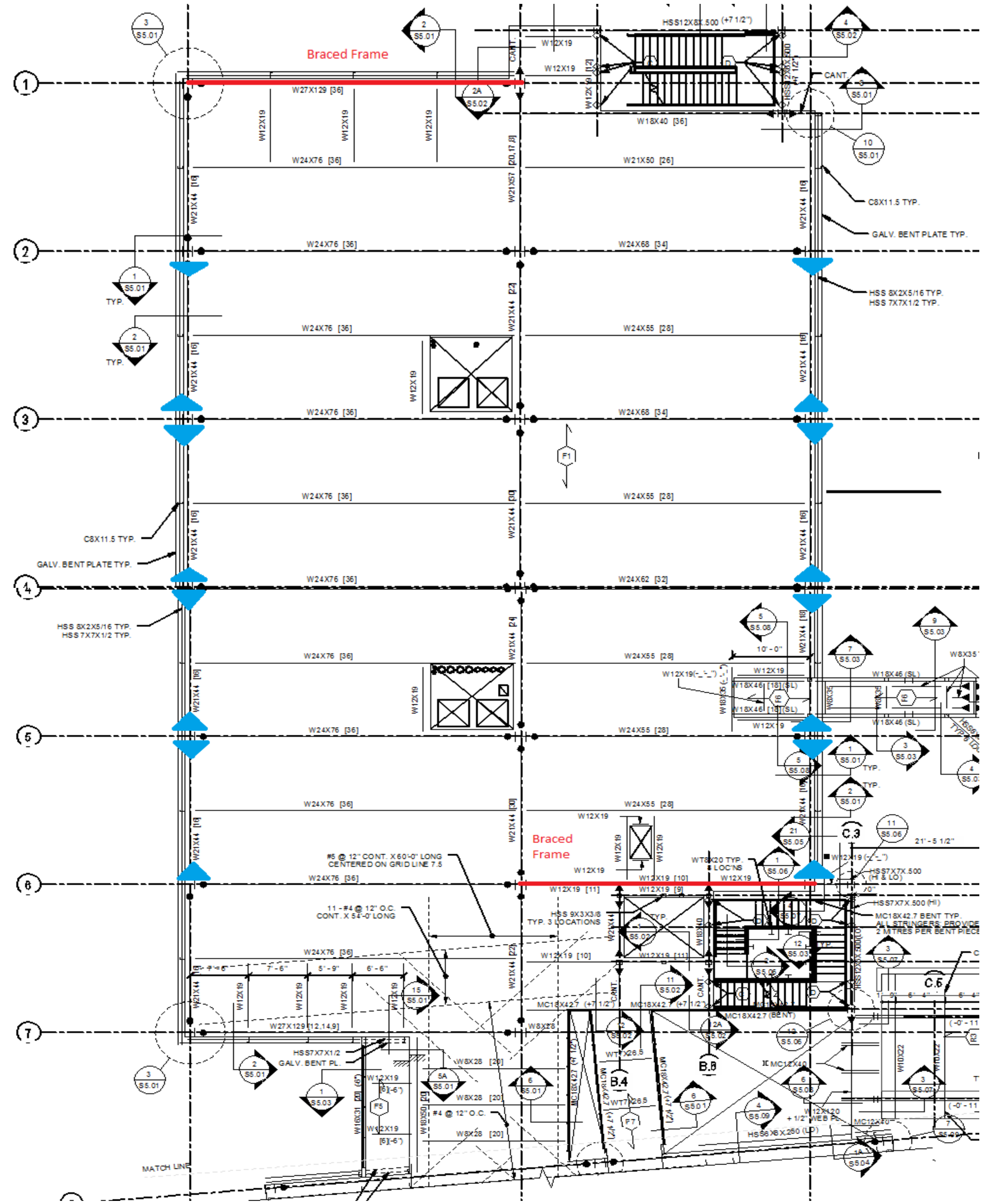


Figure 10: Revised Floor Plan for Wing C



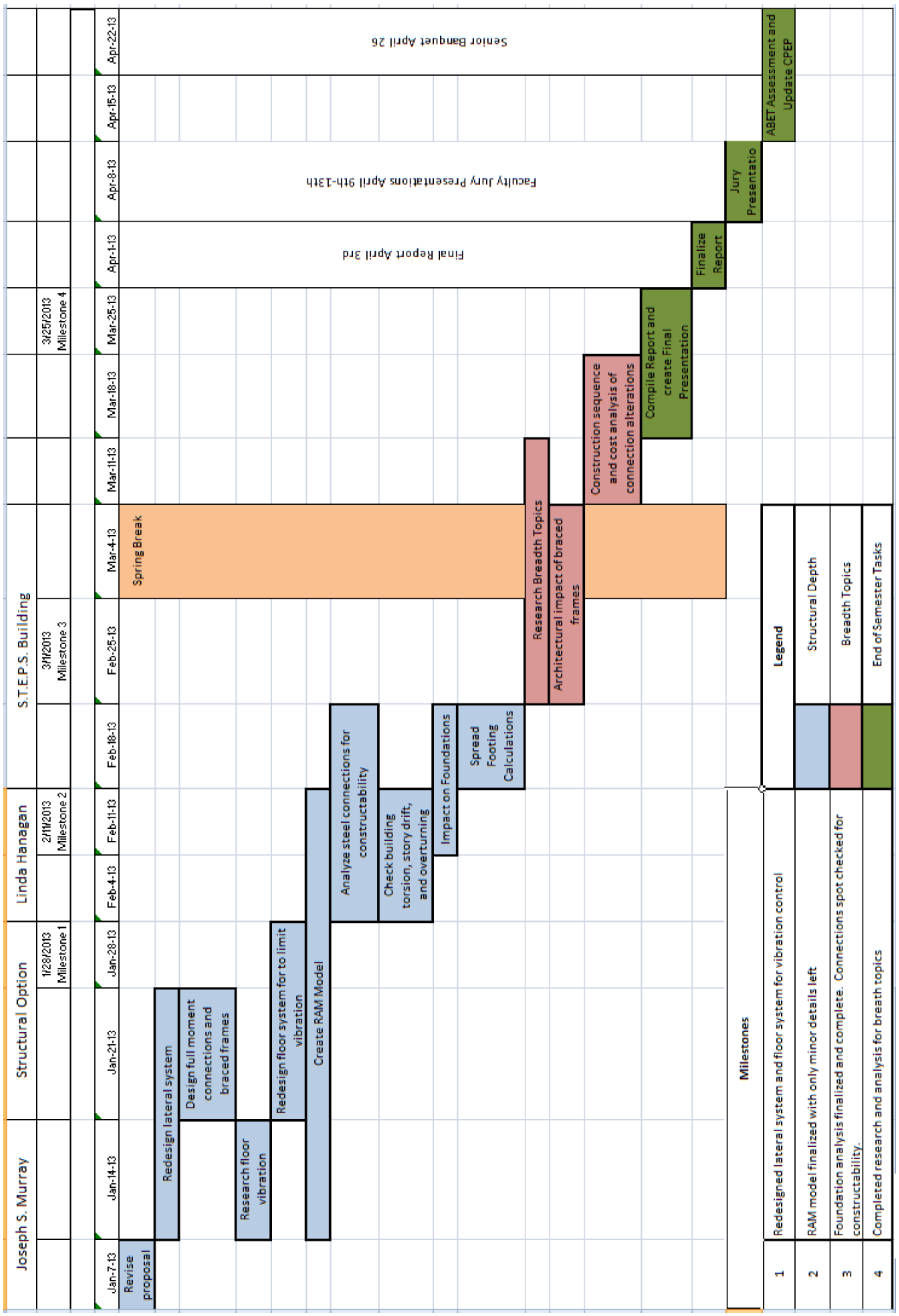
Breadth 1: Architectural

Placing braced frames in an existing building can cause unavoidable architectural impacts. As a consequence of adding braced frames to the S.T.E.P.S. Building, an architectural study of the braces must be undertaken. Any direct impact on pedestrian walkways or corridors must be understood and resolved. Other architectural considerations include braces which will be visible from interior spaces. Typical architectural plans can be found in Appendix A-1.

Breadth 2: Construction Management

Changing the connections in the building has an impact on erection sequencing, so a detailed construction sequence will be undertaken along with crane positioning for the project. This will be compared with the actual time of erection for any direct economic impact on the project. In addition, the impact of the new and existing connections on prefabrication and field welding will be examined. Working with a steel fabricator to prefabricate connections and shop weld as much as possible could have cost savings and eliminate field welds.

Proposed Schedule



Conclusion

Next semester, a thorough undertaking will examine the proposed changes to the lateral system, floor system, and steel connections. A new computer model will need to be produced to analyze the changes in the structure's behavior. Research will be done on the impact of floor vibrations in a laboratory setting and ways to dampen vibratory effects from building elements like corridors or cantilevered areas. Skills learned in AE 534 will be used to look at connections on the building and possibly redesign them for cost savings by reducing erection time.

The two breadths will also be investigated. Architecturally, the braces should be placed so they have as little impact architecturally as possible. However this is not always the case, and in the case of a conflict, there must be some resolution or compromise between the existing architecture and the proposed braced frames. From a construction management perspective, some research will need to be done into erection sequencing and crane positioning on the existing structure for comparison with the proposed changes. A comparison will also be made between the amount of prefabrication and shop welding indicated on the drawings. A possible reduction in field welding could result in cost savings.

All of this work will be done according to the proposed schedule on the previous page while reaching each milestone date with the associated work completed. This work will culminate in the completion of a final report by April 1, 2013 to allow ample time for preparation of the faculty jury presentations on April 9, 2013.

Appendix A-1

Figure 11: Floor Plan of Wing B

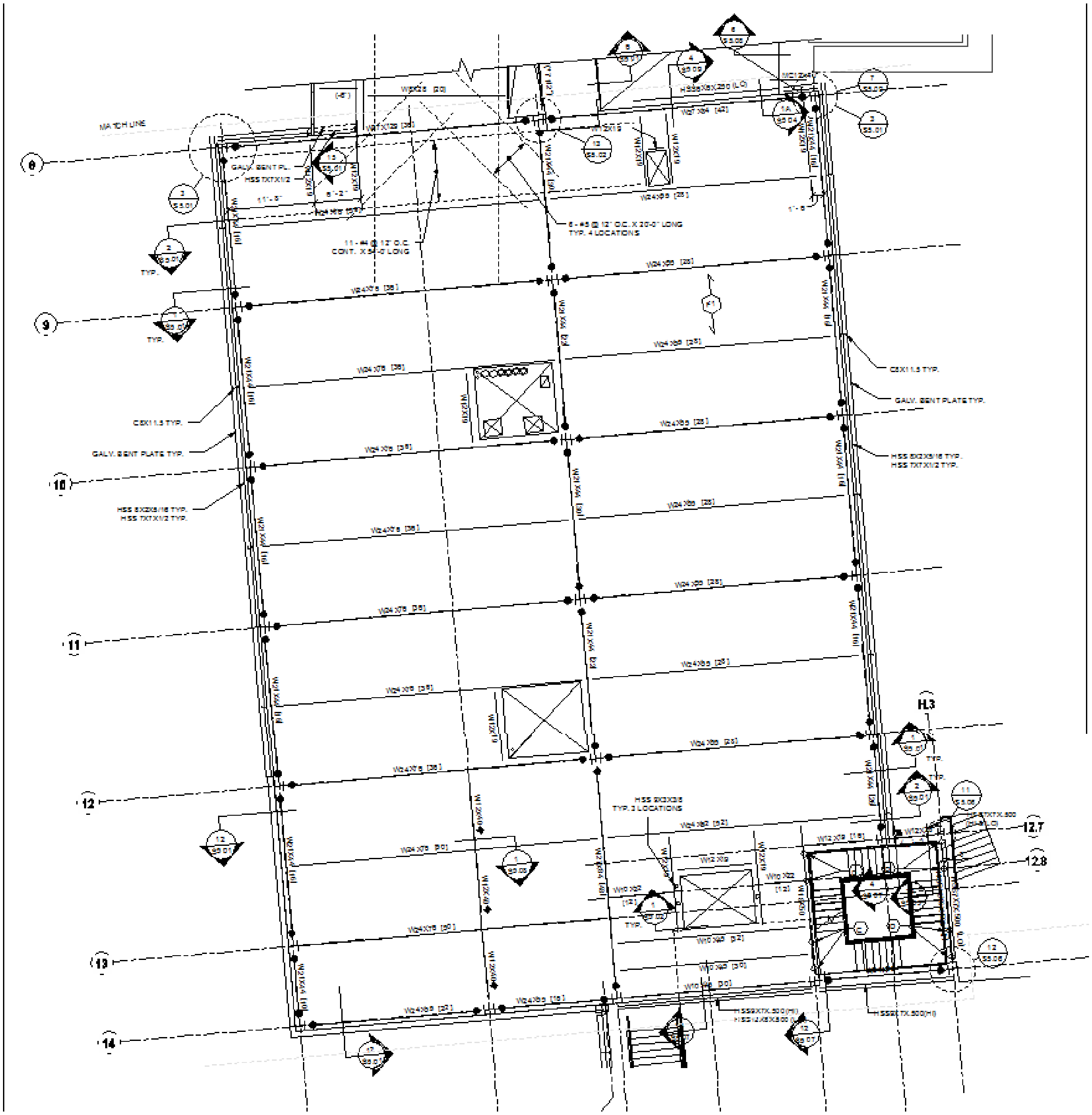


Figure 12: Floor Plan of Wing C

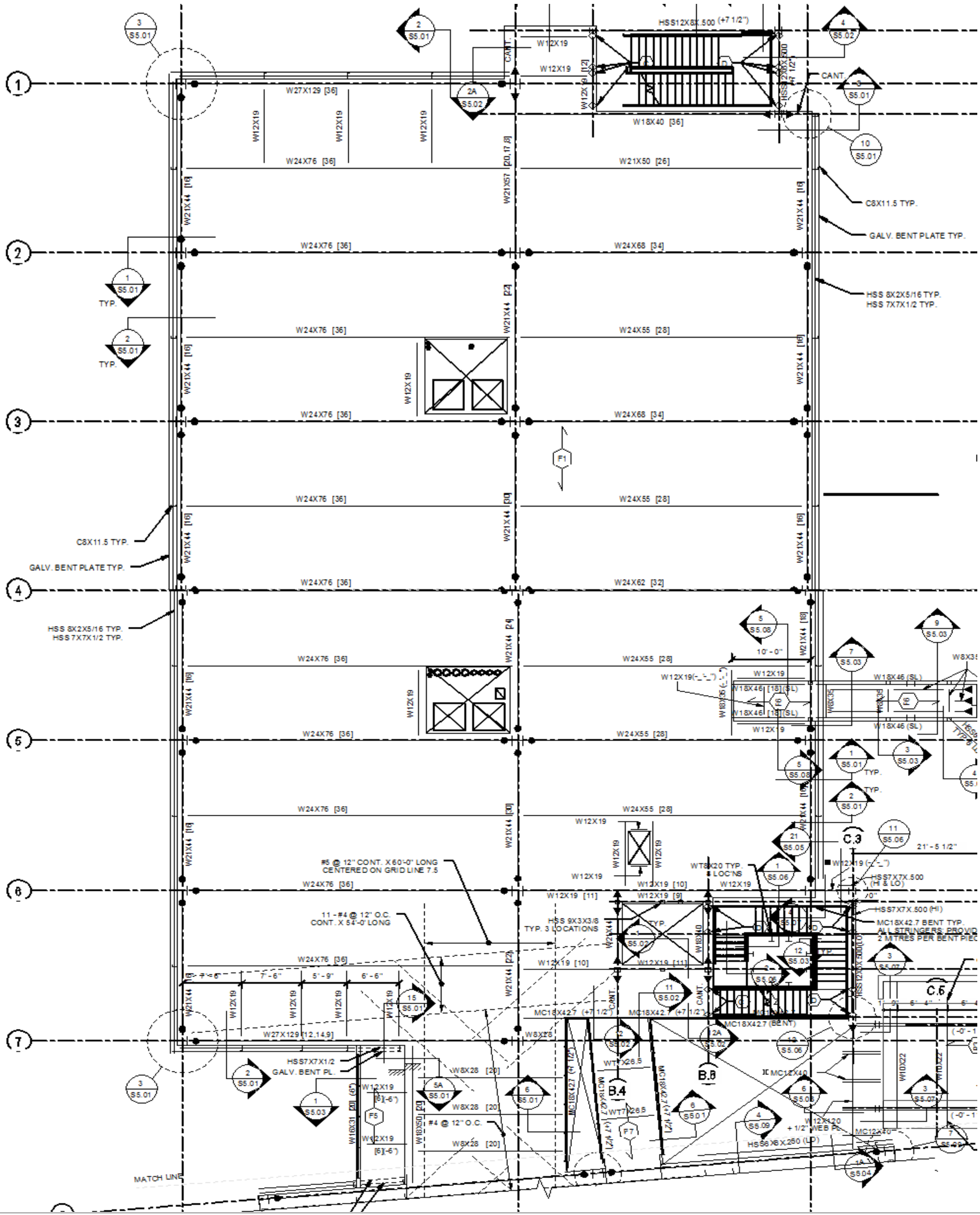


Figure 13: Typical Architectural Floor Plans

Courtesy BCJ Architects